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Acquisition and Transfer of High-Workload Skill

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Simultaneously practicing multiple tasks results in high-workload skills that may not be acquired by practicing the same tasks as single tasks. In three experiments, subjects watched a rapidly changing display and responded to consistently mapped targets in four tasks. Some subjects practiced one task at a time; some subjects practiced two tasks at a time as dual tasks; some subjects practiced combinations of single and dual tasks. After acquisition, all subjects performed transfer tasks that were multiple tasks not performed together during acquisition. The results showed a large decrease in performance when subjects were introduced to multiple tasks after training single tasks. Dual-task training resulted in nearly perfect transfer to novel task combinations. These results are discussed in terms of the practical implications of multiple-task compensatory activities.

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ACQUISITION AND TRANSFER OF HIGH-WORKLOAD SKILL

CONTENTS

Page

INTRODUCTION 1

EXPERIMENT 1 2

Method 3
Results and Discussion 5

EXPERIMENT 2 8

Method 8
Results and Discussion 8

EXPERIMENT 3 10

Method 10
Results and Discussion 11

GENERAL DISCUSSION 12

Practical Implications 12
Theoretical Considerations 12
Conclusions 13

ACKNOWLEDGMENTS 13

REFERENCES 13

LIST OF FIGURES 15

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ACQUISITION AND TRANSFER OF HIGH-WORKLOAD SKILL

INTRODUCTION

In a high-workload situation, a person must simultaneously perform multiple tasks. The workload literature has shown that subjects can perform some multiple tasks without interference after extensive practice. For example, people learned to read while taking dictation (Hirst, Spelke, Reaves, Caharack, & Neisser, 1980), shadow prose while playing a piano (Allport, Antonis, & Reynolds, 1972), cancel digits while flying complex aerial maneuvers in a simulator (Colle & DeMaio, 1978), and perform multiple search tasks (Schneider & Fisk, 1982, 1984). Although people can learn to perform in high-workload situations, the learning process requires large amounts of training, and that training is often expensive and dangerous. The purpose of this research is to better understand the acquisition and transfer of high-workload skills.

There has been extensive research to determine if it is better to train a complex skill as a whole or in parts (for reviews see Stammers, 1982; Lintern & Wickens, 1991). Many real-world, high-workload skills (e.g., piloting, programming) are learned by part-task training. The intuitive appeal of part-task training is that subsets of the complex task are easier to learn, and the assumption is that there will be positive transfer of this part-task training to performance on the whole task. Stammers (1982) reviewed the generality of this principle. On the whole, Stammers found little support for the notion that practicing parts of a task produce advantages over practicing the whole task. Differences between training groups were small, with whole training having a slight advantage. Stammers suggested that decisions about part-whole training should be made on empirical observations specific to the situation and not on some analytical principles.

Some high-workload situations involve simultaneous performance of distinctly separate tasks. Rieck, Ogden, and Anderson (1980) tested varying amounts of single- and dual-task training as preparation for dual-task performance of a tracking task and a digit classification task. The training phase was four three-minute trials. Some subjects had three practice trials on the tracking task alone followed by dual-task performance on the fourth trial. Other subjects completed two single and two dual, one single and three dual, or 4 dual-task trails. The results of the fourth trial showed that dual-task performance was a function of the amount of dual-task training; single-task training had little effect on dual-task performance relative to the dual-task training. However, the groups that had more dual-task trials also had more practice with the digit classification task. In the present experiments, we test varying amounts of single- and dual-task practice in which the groups are equated for the amount of practice with all the component tasks.

In other high-workload situations, the separation of the whole task into parts is not as clear. Mané, Adams, and Donchin (1989) and Newell, Carlton, Fisher, and Rutter (1989) examined part versus whole training of the computerized video game, the Space Fortress. Mané et al. (1989) had one group practice isolated components of the game which included control of ship movement, recognition of mines as friend or foe, and speeded button-press responses. These subjects had 14 minutes of component practice prior to the test phase, which was 20 five-minute blocks. The part-task group did perform better in the test phase than a control group that received no part-task training; however, when the two groups were equated for total time on task, the part-task group was no better than the control group. Newell et al. (1989) found that whole-game performance was better after prior practice that incorporated coordinated training emphasizing interactive movements of the ship with either the fortress or the mines than after prior practice with isolated components similar to Mané et al. (1989). These results demonstrate the importance of training coordinated elements of component skills.

High-workload Skill

Presumably some cognitive coordination skills are acquired as a result of whole-task practice that are not acquired during part-task practice. Lintern and Wickens (1991) suggested that multiple-task practice develops important timesharing skills, which involve alternation and integration strategies. Schneider and Detweiler (1988) outlined seven compensatory activities that can occur during concurrent performance of multiple tasks. One important question concerns the gerneralizability of these compensatory skills. For example, Damos and Wickens (1980) found positive transfer of dual-task training to a qualitatively different dual task. Transfer performance on a dual-axis tracking task was better following dual-task as compared to single-task training of two digit tasks. In the present experiments, we examine the degree to which dual-task practice transfers to other task combinations. A basic understanding of this high-workload transfer would improve the efficiency of training. If every possible combination of tasks in a high-workload situation must be practiced, the combinatorics quickly get out of hand (e.g. if there are 6 individual tasks there are 15 dual-task combinations to be trained). However, if there is positive transfer across combinations, the number of combinations could be reduced (e.g. if there are 6 individual tasks, training could involve just 3 dual-task combinations).

Our research focuses on an attention-loading task. Subjects view a rapidly changing display of multiple stimuli and respond to presented targets. The tasks are consistently mapped search tasks in which targets never appear as distractors. Automatic/controlled processing theory suggests that two qualitatively different forms of processing can account for the marked changes that can occur in performance with consistent practice (Schneider, Dumais, & Shiffrin, 1984; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Control processing is characterized as slow, effortful, and largely under the subject's control. Automatic processing is fast, parallel, and relatively effortless. A simple application of automatic/control processing theory to multiple-task training might advocate practicing single-task components first, prior to having the learner perform the tasks concurrently. In single-task training, components become automatic more easily and no longer require central processing. They could then, in theory, be combined to perform multiple tasks. However, the data are not compatible with this simple view (Detweiler & Lundy, 1993; Schneider & Fisk, 1984). Single-task training does not transfer well to dual-task performance. This suggests that automating a component or a set of components with single-task practice is not sufficient to produce reliable performance under conditions high, multiple-task workload. In Experiment 1 we compare varying amounts of single-task practice and all dual-task practice as preparation for transfer to novel combinations of dual tasks

One hypothesis about why dual-task practice is better than single-task practice is that a dual task provides opportunities to learn different attentional strategies. Schneider and Fisk (1982) showed that allocation of attention can influence performance in a dual task. Subjects performed a dual task that was two different letter-search tasks. One was a consistently mapped task and the other was a variably mapped task, in which letters that were targets on one trial appeared as distractors on subsequent trials. Subjects were better when they directed their attention to the variably mapped task. It may be that dual-task practice affords training for allocation of visual attention and single-task practice does not. For example, most dual tasks require that a subject attend to two stimuli; whereas, in a single-task, attention is focused on only one stimulus. Experiment 2 examines this hypothesis.

EXPERIMENT 1

Although researchers have suggested that dual-task practice results in compensatory activities (Schneider & Detweiler, 1988) and the acquisition of timesharing skills (Lintern &

Wickens, 1991), little research has specifically addressed the acquisition and transfer of this high-workload skill. In Experiment 1, subjects learned four visual target-detection tasks by practicing one task at a time, practicing two dual tasks, or practicing a mixture of the two. All subjects then transferred to dual tasks that had not been previously practiced together and to quad tasks presented at the rate of 90 stimuli per second. During acquisition, subjects practicing single tasks need only to attend and respond to one element of the display at a time, and therefore, they will detect more targets, make fewer false alarms, and respond to targets faster than subjects practicing dual tasks. We expected a decrease in performance when subjects who had practiced single tasks were first introduced to dual tasks, and we observed performance over several sessions allowing us to determine the persistence of this decrease in performance. We were most interested in whether dual-task practice would transfer to novel combinations of the dual tasks. If subjects who practiced dual tasks show a decrease in performance when transferred to novel combinations of those tasks, then the cognitive-coordination skills would be specific to practiced combinations of tasks. If, on the other hand, subjects show positive transfer to novel combinations of dual tasks, then the cognitive-coordination skills of dual-task practice would be more general.

Method

Subjects. Twenty-eight subjects were each paid $5/hr for 6 hours of participation. All subjects had normal or corrected-to-normal vision.

Materials. The experiment was presented and data were collected by IBM compatible PCs with VGA monitors programmed with the MEL software system (Schneider, 1988). The task was a multiple-frame consistently-mapped search procedure; the subject watched a rapidly changing display and pressed keys on the keyboard when targets were detected.

An example of the display for a single frame is shown in Figure 1. The display measured 22 mm vertically and 33 mm horizontally and was centered in the screen. The subject's eyes were 55 cm from the screen. The display consisted of four search domains: a word category search of a single displayed word, a letter search of two displayed letters, a symbol search of two displayed symbols, and a color search of four filled rectangles. The word appeared in all lower-case characters and was from a set of 48 common nouns (4 - 6 letters). This set had eight words in each of six categories (furniture, cities, animals, birds, vegetables, and vehicles). The two different letters in the display were from the set: G, Z, J, T, K, and L. The two different symbols in the display were from the set: ♫, ↑, ♥, Σ, ■, and ╬. Four different colors appeared in the display from the set: dark blue, yellow, light blue, red, magenta, green, and gray. Each trial included 150 rapidly presented frames. Words, letters, symbols and colors were never repeated in the same position on successive frames. Targets were the same for all subjects: furniture and cities for the word categories, G and Z for the letters, ♫ and ↑ for the symbols, and dark blue and yellow for the colors. Each target was mapped to a separate key on the bottom row of the keyboard. The eight keys were labeled as a reminder of each key's function. The subject responded to furniture words with the little finger of the left hand and to cities with the little finger of the right hand. In the same manner, the subject responded to letter, symbol and color targets with the ring, middle and index fingers, respectively.

Insert Figure 1 about here

Design and Procedure. Each subject participated in six one-hour sessions over a two-week period. The first three sessions were the acquisition phase, and the final three sessions were the transfer phase. Each subject was randomly assigned to one of three acquisition conditions which differed as to the number of targets and the number of target domains searched in each trial. The 1 target - 1 domain group searched for a single target from one domain on all trials in a block. For example, in one block, the subject searched for furniture words. In the next block, the subject searched for the letter G; in the next block, the color yellow, and so forth. The assignment of the eight target tasks to each block was randomized without replacement. The 2 targets - 1 domain group searched for two targets from a single domain on all trials in a block. The subject searched for furniture words and city words in one block, the letters G and Z in another block, the symbols ♫ and ↑ in another block, and the colors blue and yellow in another block. The assignment of the four combinations of two-target tasks to each block was randomized without replacement every four blocks. The 2 targets - 2 domain group searched for two targets with one target from each of two domains on all trials in a block. The subject searched for furniture words and the ↑symbol in one block, city words and the ♫ symbol in another block, the letter G and the color yellow in another block, and the letter Z and the color blue in another block. The assignment of the four combinations of two-target tasks to each block was randomized without replacement every four blocks. The number of subjects in the three groups, 1 target -1 domain, 2 targets - 1 domain, and 2 targets - 2 domains, were 8, 10, and 10 respectively.

Transfer was the same for all subjects. In each block of trials, a subject searched for four targets from two domains. In one block the subject performed the word and symbol search tasks, and in the next block the letter and color tasks. The order for these was counterbalanced over subjects.

There were eight blocks of trials in each session. In order to complete each session in one hour, we varied the number of trials per block. In Session 1, the subject received written and verbal instructions about the task and completed 4 trials per block. There were 7 trials per block in Sessions 2 and 3. During the acquisition phase the duration of each trial was 30 s (each of the 150 frames were displayed for 200 ms). In the transfer phase, Sessions 4, 5, and 6, the task was made progressively more difficult by reducing the frame duration. For the first four blocks of Session 4, a subject performed 7 trials per block with a frame duration of 200 ms. At the start of the fifth block in Session 4 and all through Session 5, the frame duration was reduced to 150 ms, and there were 8 trials per block. At the beginning of Session 6, the frame duration was reduced to 100 ms, and there were 10 trials per block.

The subject initiated each trial by pressing the space bar. A display appeared to remind the subject what targets would appear. The subject pressed the space bar again and the target display was replaced by the word "READY" in the center of the screen. The ready warning remained for 6-10 s, followed by a blank screen for 100 ms. Each trial consisted of 150 frames, and 8 of the 150 frames displayed a single target. Any two target frames were separated by at least 12 distractor frames. The task was to press the correct key whenever a target appeared. After each trial, the subject received feedback for the number of hits, misses and false alarms on the trial.

High-workload Skill

The dependent variables were target detection measured as the percentage of hits (calculated as (hits / targets) * 100), the number of false alarms, and the average response time for hits. A correct keypress was scored as a hit if the subject responded between 200 and 1300 ms after a target appeared. All other keypresses were scored as false alarms. Typically, subjects made few false alarms, and these data are discussed only when significant effects for false alarms influences the interpretation of the other measures. At the end of each block of trials, the subject received feedback for the percentage of hits and the total number of false alarms in the block. The subject rested for 30 s between blocks.

Results and Discussion

Acquisition hits. The ability to detect and correctly respond to targets during the first three sessions was a function of acquisition condition and practice session. Subjects improved over the acquisition phase, and subjects in the 1 target - 1 domain and 2 targets - 1 domain groups were better than subjects in the 2 targets - 2 domains group. The difference between attending to one or two task domains had a significant effect on target hits during acquisition, whereas the number of targets did not have an effect.

The left side of Figure 2a shows the performance measured as the mean percentage of hits for the three groups for each half-session during acquisition. An analysis of variance (ANOVA) revealed significant main effects of acquisition condition ($F(2,25) = 26.28$, $p < .0001$, $MSe = 148.85$) and practice ($F(5,125) = 110.28$, $p < .0001$, $MSe = 25.13$) and a significant interaction between acquisition condition and practice session for the percentage of hits ($F(10,125) = 8.75$, $p < .0001$, $MSe = 25.13$). The interaction suggests that the differences among the groups were greater at the beginning than at the end of acquisition. This is likely the result of a ceiling effect; subjects in the 1 target - 1 domain and 2 target - 1 domain groups were nearly perfect in terms of target detection by the end of the acquisition phase. Bonferroni t-tests on the mean performance of the three groups at the beginning and end of acquisition revealed a significant difference between the 2 targets - 2 domains group and the other two groups. In the first half-session, the mean percentage of hits of the 2 target - 2 domains group ($M = 50$) was significantly less than the mean of the 2 targets - 1 domain group ($M = 71$; $t(25) = 4.37$, $p < .0002$) and than the mean of the 1 target - 1 domain group ($M = 82$; $t(25) = 6.26$, $p < .0001$). The difference between the 2 target - 1 domain and 1 target - 1 domain groups was not significant ($p = .04$; Bonferroni cutoff $p = .016$). At the end of the acquisition phase, the last half-session of Session 3, the mean percentage of hits of the 2 target - 2 domains group ($M = 89$) was significantly less than the mean of the 2 targets - 1 domain group ($M = 97$; $t(25) = 3.88$, $p < .001$) and than the mean of the 1 target - 1 domain group ($M = 96$; $t(25) = 3.28$, $p < .005$).

Insert Figure 2 about here

Acquisition false alarms. The mean number of false alarms per trial during the first three sessions was a function of acquisition condition and practice session. Subjects reduced the number of false alarms over the acquisition phase, and subjects in the 1 target - 1 domain group made fewer false alarms than subjects in the 2 targets - 1 domain and 2 targets - 2 domains groups. The difference between the number of targets had a significant effect on false alarms during acquisition, whereas attending to one or two task domains did not have an effect.

High-workload Skill

The left side of Figure 2b shows the performance measured in the mean number of false alarms per trial for the three groups for each half-session during acquisition. An ANOVA revealed significant main effects of acquisition condition ($F(2,25) = 3.91$, $p < .05$, $MSe = 0.691$) and practice ($F(5,125) = 20.56$, $p < .0001$, $MSe = 0.109$). The interaction between acquisition condition and practice session did not reach significance ($F(10,125) = 1.63$, $p > .10$).

Transfer hits. During the transfer sessions, all groups performed the same tasks which required searching for four targets from two domains; on some blocks they searched for words and symbols, and on other blocks they searched for letters and colors. The right side of Figure 2a shows the detection performance for the three groups over the three transfer sessions. The shape of these curves as a function of transfer session are somewhat the result of the reduction in frame duration in the middle of the fourth and the beginning of the sixth sessions. An ANOVA revealed a significant interaction between acquisition condition and transfer session ($F(10,125) = 6.91$, $p < .0001$, $MSe = 20.01$). Figure 2a suggests that early in transfer subjects in both the 2 targets - 2 domains group and the 2 targets - 1 domain group detected a greater percentage of targets than subjects in the 1 target - 1 domain group and that these differences declined over transfer sessions. Bonferroni t-tests on the mean performance of the three groups at the beginning and end of supported this description. In the first half-session of transfer, the mean percentage of hits of the 1 target - 1 domain group ($M = 67$) was significantly less than the mean of the 2 targets - 1 domain group ($M = 84$; $t(25) = 3.93$, $p < .001$) and than the mean of the 2 targets - 2 domains group ($M = 88$; $t(25) = 4.87$, $p < .0001$). The difference between the 2 target - 1 domain and 2 targets - 2 domains groups was not significant ($p > .3$). At the end of the transfer phase, the last half-session of Session 6, there were no significant differences among the groups.

For the dual-task transfer task, the difference in performance for detecting targets (Figure 4A) between the two groups that practiced dual tasks during acquisition (the dual- and mixed-task groups) and the single-task group declined over transfer sessions. For the percentage of hits, the interaction between acquisition condition and transfer session was significant ($F(6,75) = 5.23$, $p < .0005$, $MSe = 16.94$). Follow-up tests revealed marginally significant differences among the three groups for the first half-session of transfer ($F(2, 25) = 3.34$, $p = .08$, $MSe = 266.42$). A similar ANOVA for the number of false alarms was significant ($F(2,25) = 4.24$, $p < .05$, $MSe = 2.294$). Follow-up t-tests confirmed that the single-task group made more false alarms per trial ($M = 2.74$) than the dual-task group ($M = .87$, $t(25) = 2.47$, $p < .025$) and the mixed-task group ($M = .92$, $t(25) = 2.65$, $p < .025$). In the final half-session of dual-task transfer, there were no significant differences among the groups ($F < 1.0$). The response time measure (Figure 4B) showed a similar pattern. The interaction of acquisition condition and transfer session was significant ($F(6,75) = 3.28$, $p < .01$, $MSe = .00048$); there were significant differences among the groups in the first half-session of transfer ($F(2, 25) = 6.66$, $p < .005$, $MSe = .0040$); and no significant differences in the last half-session ($p > .05$). These results suggest that the single-task group acquired the skills associated with dual-task compensatory activities during the transfer sessions, much like the mixed-task group acquired those skills after switching from a single task to a dual task midway through the acquisition sessions.

Insert Figure 4 about here

High-workload Skill

The results of the quad task in transfer showed a pattern similar to the dual tasks (see Figure 4). However, the effects concerning acquisition condition did not reach statistical significance.

Summary. These results support the notion that compensatory activities are an important characteristic of dual tasks. When subjects trained with single tasks were transferred to a dual task, their performance dropped relative to their single-task baseline. When the mixed-task group switched from single-task to dual-task practice, performance dropped below that of the dual-task group, albeit better than the baseline, initial performance of the dual-task group. Similarly, when the single-task group transferred to a dual task, performance suffered in both target detection and response time. In transfer, single-task practice was not as beneficial as dual-task practice, even though during the acquisition sessions subjects in the single-task group detected more targets and were faster to respond.

More importantly, both the dual-task and the mixed-task groups showed no deficit in performance at the beginning of transfer. As a basis of comparison, performance was estimated for what the dual-task group would have been if they had continued to perform the same dual tasks. This was a linear extrapolation of the last two half-sessions of acquisition. The percent of transfer was calculated from the ratio of performance of each experimental group during the first half-session of transfer divided by the extrapolated estimate for the dual-task group. The percent of transfer was 72.5 % for the single-task group and 89.6% for the mixed-task group. Transfer for the dual-task group to novel combinations of dual tasks was 93.6%. This metric shows that the performance on the novel combinations was nearly as good as the projected performance of the original combinations. These results suggest that the compensatory activities acquired during dual-task practice transferred to novel combinations of those tasks.

EXPERIMENT 2

One purpose of Experiment 2 was to replicate the strong positive transfer to novel combinations found in Experiment 1. In Experiment 1, the frame duration was gradually reduced over the five sessions of acquisition. Its was possible that the lengthy frame duration in the early sessions promoted performance for the dual-task group and did not provide enough of a challenge for the groups practicing single tasks. Therefore, in Experiment 2, all sessions had a frame duration of 200 ms per frame. Pilot testing showed that 200 ms was short enough to cause the initial performance of the dual-task group to be near chance and long enough to keep subjects from feeling helpless. Also, acquisition in Experiment 2 was reduced to three sessions for a total of 144 trials. One hypothesis was that under these conditions the mixed-task group might outperform the dual-task group in transfer. The early single-task practice would allow the mixed-task group to achieve a greater number of target detections prior to switching to dual-task practice.

A second purpose of Experiment 2 was to test if the dual-task skill acquired in Experiment 1 was the result of learning to attend to multiple items in the display. In Experiment 1, the positive transfer of dual-task practice to novel combinations of dual tasks suggests that dual-task skill involves more than merely learning where to visually attend. In acquisition, subjects who practiced dual tasks learned to attend to words combined with colors and to letters combined with symbols. In transfer, these subjects had no trouble attending to words combined with symbols and to letters combined with colors. However, dual-task skill could be the result of practice involving visual attention to more than one task at a time. During acquisition, the single-task group never visually attended to two items in the display at the same time. However,

during acquisition the single-task group did learn two target-to-response mappings (e.g. when they practiced the word category search, they pressed one key in response to furniture words and another key in response to cities). Therefore, what we have called a single task in Experiment 1 has implied characteristics of a dual task in terms of the number of target-to-response mappings. In Experiment 2, we included an individual-target condition; during acquisition, these subjects visually attended to a single item in the display (e.g., the words) just like the single-task group. However, on each trial, subjects searched for exemplars from one target category (e.g., furniture). Therefore, the demands on visual attention were the same for the individual-target and the single-task groups. If the skill acquired in dual-task practice is merely the ability to visually attend to two items in the display at the same time, then the individual-target and single-task group should be no different in transfer.

Method

Subjects. Thirty-eight subjects (14 males and 24 females) were each paid $5/hr for six hours of participation. All subjects had normal or corrected-to-normal vision. Three subjects did not complete the six sessions, and data from those subjects were not included in the analyses.

Materials, Design, and Procedure. The materials and tasks were the same as in Experiment 1. Each subject participated in six one-hour sessions over a two-week period. The first three sessions were the acquisition phase, and the final three sessions were the transfer phase. Each subject was randomly assigned to one of four acquisition conditions. The single-task and dual-task conditions were the same as in Experiment 1. Acquisition for the mixed-task group was identical to the single-task group for the first 1½ sessions and identical to the dual-task group for the following 1½ sessions; they switched from single-task to dual-task training after 60 of the 144 total trials in acquisition. The individual-target group visually attended to one task and searched for a single target on all trials in a block. For example, in one block, the subject would attend to the words and search for furniture. In another block, the subject would attend to the words and search for cities. The assignment of the eight individual targets to each block was randomized for each subject prior to each acquisition session. The number of subjects in the single-task, dual-task, mixed-task, and individual-target groups were 8, 11, and 9 respectively.

The frame duration was 200 ms for each of the 150 frame displays in a trial. There were eight blocks of trials in each session. In the first session, there were four trials per block, so that subjects could receive instructions and still complete the session in one hour. In all other sessions, there were seven trials per block. Transfer was the same as the dual-task transfer in Experiment 1. It was the same for all subjects with a frame duration of 200 ms.

Results and Discussion

Acquisition. Targets-detection and response-time performance during the three acquisition sessions were a function of acquisition condition and practice sessions. Analysis of variance revealed a significant interaction between acquisition condition and practice session for the percentage of hits ($F(15,155) = 17.36$, $p < .0001$, $MSe = 48.75$) and for response time ($F(15,155) = 21.68$, $p < .0001$, $MSe = .0014$). Figure 5A shows the performance measured in the percentage of hits and Figure 5B shows the response-time data of the four groups for each half-session during acquisition. These interactions were largely a result of the drop in performance for the mixed-task group when they were switched from practicing single tasks to dual tasks midway through the second session. Target-detection and reaction-time performance for the mixed-task group was similar to the single-task group for the first 1½ sessions, and similar to the dual-task group for the last 1½ sessions of acquisition. T-tests showed no significant differences in target-

detection and reaction-time performance between the mixed- and dual-task groups during the second half of Session 2, after the mixed-task group had switched to dual tasks. However the mean number of false alarms per trail for the mixed-task group (M = 1.37) was significantly greater than for the dual-task group (M = .49), $t(15) = 3.95$, $p < .002$. Subjects in the individual-target condition were near ceiling at detecting targets, similar to the single-task condition, and were faster to respond to targets than all other conditions throughout acquisition. At the end of acquisition, there were still significant differences among the four groups in target detection ($F(3,31) = 9.59$, $p < .0005$, $MSe = 58.13$) and in response time to targets ($F(3,31) = 65.81$, $p < .0001$, $MSe = .0026$).

Insert Figure 5 about here

Transfer. Figure 6 shows the target-detection and response-time performance of the four groups for the last half-session of acquisition and the first half-session of transfer. The interactions shown in Figures 6A and 6B were significant (for the percentage of hits, $F(3,31) = 34.80$, $p < .0001$, $MSe = 52.54$; for response time, $F(3,31) = 110.77$, $p < .0001$, $MSe = .0014$). The detection and response-time performance of the dual-task and the mixed-task groups showed no difference between the end of acquisition and the beginning of transfer to novel combinations of dual tasks. This near-perfect transfer is a replication of the results of Experiment 1. As expected, performance of the single-task group dropped significantly, (for the percentage of hits, $t(9) = 4.37$, $p < .005$; for response time, $t(9) = 14.00$, $p < .0001$). Likewise, the performance of the individual-target group dropped from the end of acquisition to the beginning of transfer, (for the percentage of hits, $t(7) = 8.58$, $p < .0001$; for response time, $t(7) = 15.17$, $p < .0001$).

Insert Figure 6 about here

Figure 7 shows the target-detection and response-time performance for the dual transfer tasks of the four groups over the three transfer sessions. The figures show that the differences in performance among the groups were greater early in transfer. For the percentage of hits, the interaction between acquisition condition and transfer session was significant ($F(15,155) = 6.39$, $p < .0001$, $MSe = 29.35$). Follow-up tests revealed significant differences among the four groups for the first half-session of transfer ($F(3,31) = 11.89$, $p < .0001$, $MSe = 130.73$). Follow-up Bonferroni t-tests revealed that the individual-target group was significantly worse at detecting targets than the other three groups (all $p < .001$). The differences between the single-task and the dual-task groups ($p = .06$) and between the single-task and mixed-task groups ($p = .08$) were only marginally significant. In the final half-session, there were no significant differences among the groups ($F < 1.0$). For response times (Figure 7B), the interaction of acquisition condition and transfer session was significant ($F(15,155) = 2.81$, $p < .001$, $MSe = .00092$); there were also significant differences among the groups in the first half-session of transfer ($F(3,31) = 3.96$, $p < .05$, $MSe = .0049$); and no significant differences in the last half-session ($p > .05$).

Insert Figure 7 about here

Summary. As in Experiment 1, the results of Experiment 2 showed nearly perfect transfer of performance from dual-task practice to novel combinations of the dual tasks. For the dual-

task group, transfer performance for target hits was 100% of the projected performance of the original dual-task combinations. This near perfect transfer suggests that the skills acquired from dual-task practice are not specific to the combinations of practiced tasks. Both the dual-task group and the mixed-task group (99.3%) showed this nearly perfect transfer. Given that the frame duration was fixed at 200 ms and that the total number of trials in acquisition was reduced, we thought that the mixed-task group might outperform the dual-task group. Even though early single-task practice allowed the mixed-task group to detect a greater number of targets, there was no benefit at the end of acquisition or in transfer. After switching to a dual task, the performance of the mixed-task group was no different than the dual-task group.

The results of the individual-target group suggests that the skills acquired during dual-task practice are more than merely learning to simultaneously visually attend to two items in the display. The demands on visual attention were the same for the single-task and individual-target groups; both groups attended to only one item in the display during acquisition. The percent of transfer was 66.0% for the individual-target group and 86.5% for the single-task group. The individual-target group was significantly worse at detecting targets at the beginning of transfer when both these groups were first exposed to a dual task. During acquisition, the single-task group was exposed to an important characteristic of dual tasks; they did learn two target-to-response mappings. The difference in transfer between the single-task and the individual-target groups suggests that the skill acquired in dual-task practice involves the ability to map multiple targets onto separate responses. As in Experiment 1, these differences were reduced as a result of the practice afforded by the transfer sessions.

EXPERIMENT 3

The results of Experiments 1 and 2 suggested that compensatory activities practiced in a dual task transfer well to novel combinations of the paired tasks. The dual-task skill was generalizable across pairs of skills trained as dual tasks. Experiment 3 tested whether positive transfer is limited to tasks trained as dual tasks. In Experiment 3, subjects practiced two of the tasks as single tasks and two as a dual task. The transfer dual tasks paired one task trained as a single task with one of the tasks trained as a dual task. If the compensatory activities of dual tasks are limited to tasks trained as a dual task, then performance in the transfer dual task should be better for the task trained as a dual task than the task trained as a single task.

Method

Subjects. Twenty-four subjects (7 males and 17 females) were each paid $5/hr for six hours of participation. All subjects had normal or corrected-to-normal vision. One subject did not complete the six sessions, and data from that subject were not included in the analyses.

Materials, Design, and Procedure. The materials and tasks were the same as in Experiments 1 and 2. As in Experiment 2, each subject participated in six one-hour sessions over a two-week period; the first three sessions were the acquisition phase, and the final three sessions were the transfer phase. During acquisition, each subject practiced two of the tasks as a dual task and two of the tasks as single tasks. For example, a subject had a block of trials with the dual-task combination of letters and symbols; individual keypress responses were made for any occurrence of two target letters or two target symbols. In another block of trials, the subject would have the word task as a single task, responding to furniture words and to cities. In a separate block, the subject would have the colors task as a single task, responding to dark blue and yellow rectangles. Each session was eight blocks -- four with the dual task and two blocks each with the single tasks. The order in which tasks were assigned to blocks was randomized for

every subject at the beginning of every session. The assignment of which tasks were practiced as dual tasks was counterbalanced over subjects; half of the subjects practiced the tasks as described above, and half practiced the words and colors as a dual task and the letters and symbols each as single tasks. As in Experiment 2, the transfer tasks for all subjects were dual tasks combining words with symbols and letters with colors.

As in Experiment 2, the duration of each frame during acquisition was 200 ms and there were four trials per block in the first session and seven trials per block in the second and third sessions. For the first half-session of transfer (Session 4), the frame duration and number of trials per block was the same as in acquisition. For the second half of Session 4 and all of Session 5, the frame duration was to 150 ms and there were 8 trials per block. In Session 6, the frame duration was 100 ms with 10 trials per block.

Results and Discussion

Acquisition. The within-subject single- and dual-task acquisition performance in Experiment 3 was similar to the between-subject single- and dual-task acquisition performance in Experiment 2. The left sides of Figures 8A and 8B show the acquisition performance for targets trained in a single task and targets trained in a dual task. The acquisition data clearly show that subjects were better and faster at detecting targets practiced as a single task (for the percentage of hits, $F(1,22) = 127.13$, $p < .0001$, $MSe = 375.1$; for response time, $F(1,22) = 187.14$, $p < .0001$, $MSe = .0098$). Subjects improved as a function of the acquisition practice sessions (for the percentage of hits, $F(5,110) = 227.79$, $p < .0001$, $MSe = 54.87$; for response time, $F(5,110) = 14.04$, $p < .0001$, $MSe = .0024$). For target detection, the interaction between acquisition condition and transfer session was significant ($F(5,110) = 23.32$, $p < .0001$, $MSe = 43.95$); the difference in detection performance between single- and dual-task practice was less at the end of acquisition than at the beginning of acquisition .

Insert Figure 8 about here

Transfer. The right sides of Figures 8A and 8B show the dual-task transfer performance for targets trained in a single task and targets trained in a dual task. Performance on the part of the transfer dual task that had been trained in a dual task was no better than performance on the part of the transfer dual task that had been trained in a single task.. Collapsing over transfer sessions, the mean percentage of hits for the tasks trained as a single task was 84.9, and the mean for tasks trained as dual tasks was 81.4. In transfer, there were no statistically significant differences between tasks trained as single tasks and tasks trained as dual tasks. As in previous experiments, subjects showed positive transfer of detection performance for targets trained in a dual task; that is, there was no difference in the percentage of hits for targets trained in a dual task between the end of acquisition and the beginning of transfer (all $p > .05$). Pairing a task trained in a dual task with a task trained in a single task did not cause a drop in detection performance for the task trained as a dual task. There was, however, an increase in response time to targets trained in a dual task between the end of acquisition and the beginning of transfer ($t(22) = 6.44$, $p < .0001$).

Summary. There were no differences in performance of tasks that made up the transfer dual tasks as a function of whether those tasks had been practiced during acquisition in a dual task or in a single task.

GENERAL DISCUSSION

Practical Implications

The results of these experiments suggest principles of training for high-workload tasks that require responses to various combinations of target stimuli.

Cost of increased workload. There is a significant and abrupt decrease in performance in transfer from training a set of tasks as single tasks to performing combinations of those tasks together. In Experiments 1 and 2, there was a decrease in performance when the mixed-task groups switched from single- to dual-task practice. The effect was even more dramatic for the individual-target group in Experiment 2 when first exposed to dual tasks in the transfer phase. The practical implication is that it would be unwise to increase the workload for the first time in a critical situation. Just because someone is proficient at a set of individual tasks does not mean that they will be able to adequately perform those tasks together. The importance of multiple-task training is often overlooked because it seems that single-task practice will make it easier to learn the individual tasks. During initial acquisition of target detection skill, single-task practice produces more hits, fewer false alarms, and faster responses to targets. However, single-task practice does not allow learning of cognitive coordination skills or timesharing skills (Lintern & Wickens, 1991) among the tasks; it is the lack of these coordination skills that cause the decrease in performance for combined tasks. For the tasks we studied, the decrement in transfer from single-task practice, as compared to dual-task practice, was not long lasting. In Experiments 1 and 2, this was revealed in the transfer results and in the later parts of acquisition when the mixed-task group switched from single task to dual task. There may be multiple-task situations in which an alternation of single-task and dual-task practice would be beneficial both in training and in transfer to novel combinations of the tasks; however in these experiments, no mixture of single- and dual-task practice was better than all dual-task practice from the beginning.

Positive transfer to novel dual-task combinations. In many situations it would be unreasonable, and at least extremely time consuming, to train every possible combination of tasks. The results of these experiments suggest that it is not necessary to practice every combination; positive transfer can be expected from one combination to another. Experiments 1 and 2 showed nearly perfect transfer to novel combinations of dual-tasks. Furthermore, Experiment 3 showed that performance of the transfer dual tasks was quite good even though only one task in each transfer pair had been trained in a dual task. Figure 9 shows a comparison, across Experiments 2 and 3, of the performance at the beginning of transfer (to the point at which all experimental procedures were identical). The mean performance in transfer of subjects in Experiment 3--who had practiced one task of each transfer pair in a dual task and the other in a single task--was lower than subjects in Experiment 2 that had practiced all tasks as dual tasks. However, performance of subjects in Experiment 3 was greater than subjects in Experiment 2 that had practiced all tasks as single tasks or as individual targets.

Insert Figure 9 about here

Theoretical Considerations

Performing two consistently mapped tasks together as a dual task results in dual-task skill that is a generalizable ability to integrate tasks. The difference in transfer between the single-task group and the individual-target group suggests that this skill is not the result of learning how to

visually attend to two items in the display at the same time. Both these groups had to visually attend to only one item during acquisition, and there were large differences in transfer between these two groups.

The theoretical concept of dual-task skill that is the result of practicing two tasks together was termed compensatory activities by Schneider and Detweiler (1988), and timesharing skill by Lintern and Wickens (1991). There are many similarities in the two theoretical descriptions. Both included the possibility of strategic shifts; for example, learning to perform a dual task by sequentially performing one and then the other task was called shedding, delaying, and pre-loading (Schneider & Detweiler, 1988) and an alternation strategy (Lintern & Wickens, 1991). Because our experiments involved a rapidly changing multiple-frame procedure, we believe that our results demonstrate aspects of dual-task skill that require cognitive coordination, what Lintern and Wickens (1991) termed task integration. Schneider and Detweiler (1988) described three compensatory activities that involve task integration. These compensatory activities reduce interference of information transmitted among modular units required to perform multiple tasks. Multiplexing transmissions involves combining several transmissions so they share a common pathway. Shortening transmissions involves reducing the duration of time that information occupies a transmission pathway. For single tasks, a longer duration may improve the reliability of a transmission; for multiple tasks, a shorter duration may reduce the interference of competing transmissions. Converting interference from concurrent transmissions involves changing the message-specific nature of competing transmissions so that characteristics of each message are more discernible on the receiving end. It is a question for our future modeling research to investigate how these three compensatory activities might help account for the patterns of data in these experiments.

Conclusions

These experiments demonstrate the practical and theoretical importance of integrated practice for component tasks in a high-workload situation. Simultaneously practicing multiple tasks results in high-workload skills that may not be acquired by practicing the same tasks as single tasks. Furthermore, these high-workload skills transfer to novel combinations of tasks trained in single- and dual-task conditions.

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LIST OF FIGURES

Figure 1. Example of the screen display for one of the 150 frames presented each trial. The different patterns in the four rectangles represent different colors.
Figure 2. Figure A shows the target-detection performance measured in the percentage of hits. Figure B shows the response-time performance for hits. Each figure shows the three acquisition conditions as a function of each half-session of acquisition in Experiment 1.
Figure 3. Figure A shows target-detection performance measured in percentage of hits, and Figure B shows response time for the three acquisition conditions at the last half-session of acquisition and the first half-session of transfer in Experiment 1.
Figure 4. Figure A shows target-detection performance measured in percentage of hits, and Figure B shows response time for the three acquisition conditions performing the transfer dual tasks and quad task over half-session intervals of the three transfer sessions in Experiment 1.
Figure 5. Figure A shows target detection performance measured in percentage of hits, and Figure B shows response time for the four acquisition conditions for each half-session of the three acquisition sessions in Experiment 2.
Figure 6. Figure A shows target detection performance measured in percentage of hits, and Figure B shows response time for the four acquisition conditions at the last half-session of acquisition and the first half-session of transfer in Experiment 2.
Figure 7. Figure A shows target detection performance measured in percentage of hits, and Figure B shows response time for the four acquisition conditions performing the transfer dual tasks for each half-session of the three transfer sessions in Experiment 2.
Figure 8. Figure A shows target detection performance measured in percentage of hits, and Figure B shows response time during acquisition and transfer half-sessions in Experiment 3 for those tasks acquired as a single task and those tasks acquired as dual tasks.
Figure 9. Figure A shows target detection performance measured in percentage of hits, and Figure B shows response time for all acquisition conditions for the first half-session of transfer in Experiment 2 and 3.

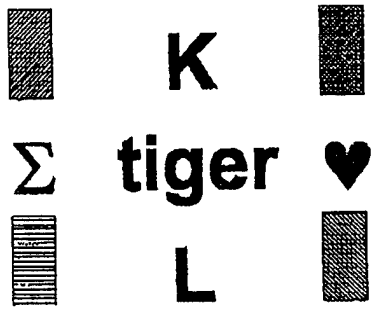
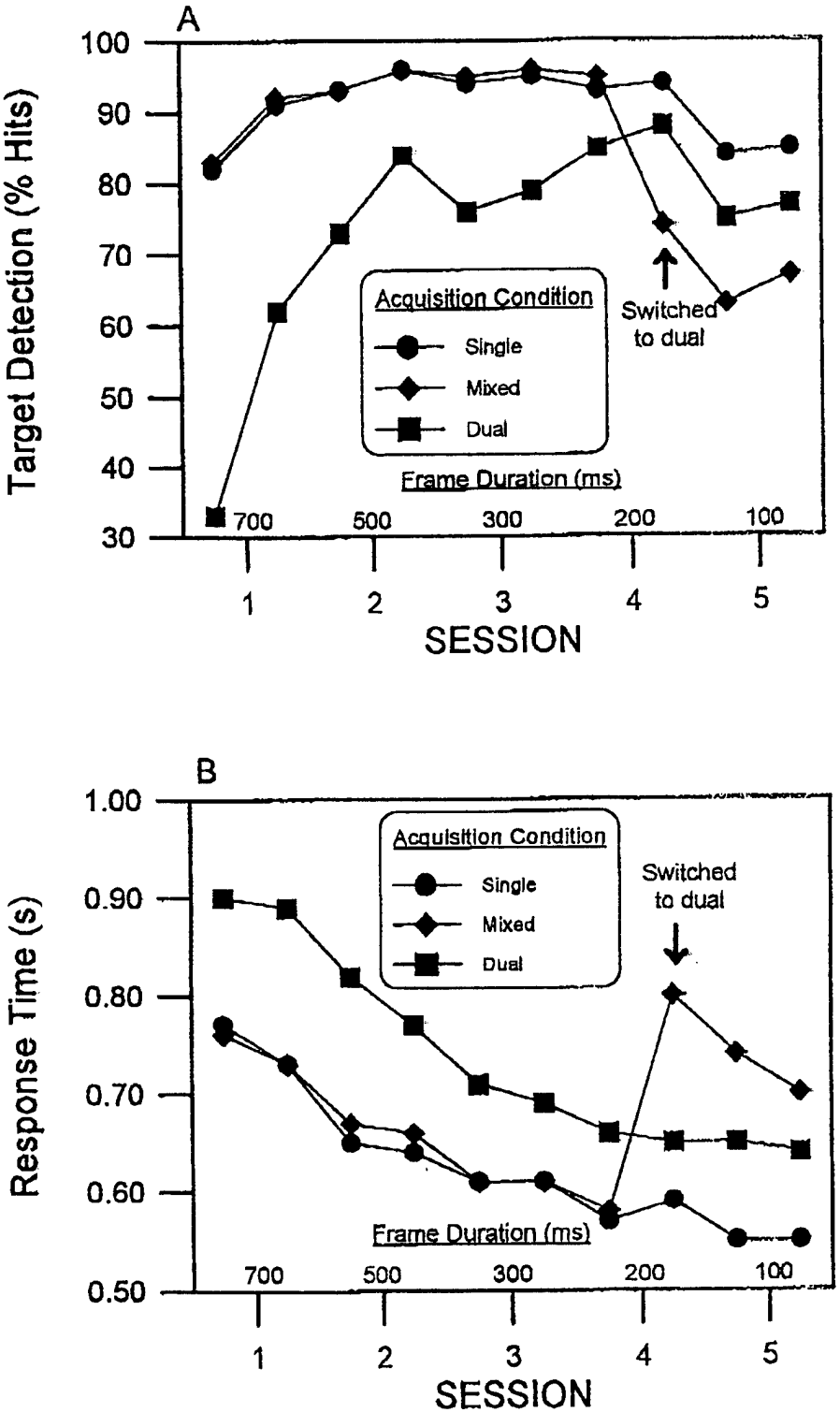


Fig. 1


A
Target Detection (% Hits)
100
90
80
70
60
50
40
30
Acquisition Condition
Single
Mixed
Dual
Switched to dual
Frame Duration (ms)
700
500
300
200
100
1
2
3
4
5
SESSION
B
Response Time (s)
1.00
0.90
0.80
0.70
0.60
0.50
Acquisition Condition
Single
Mixed
Dual
Switched to dual
Frame Duration (ms)
700
500
300
200
100
1
2
3
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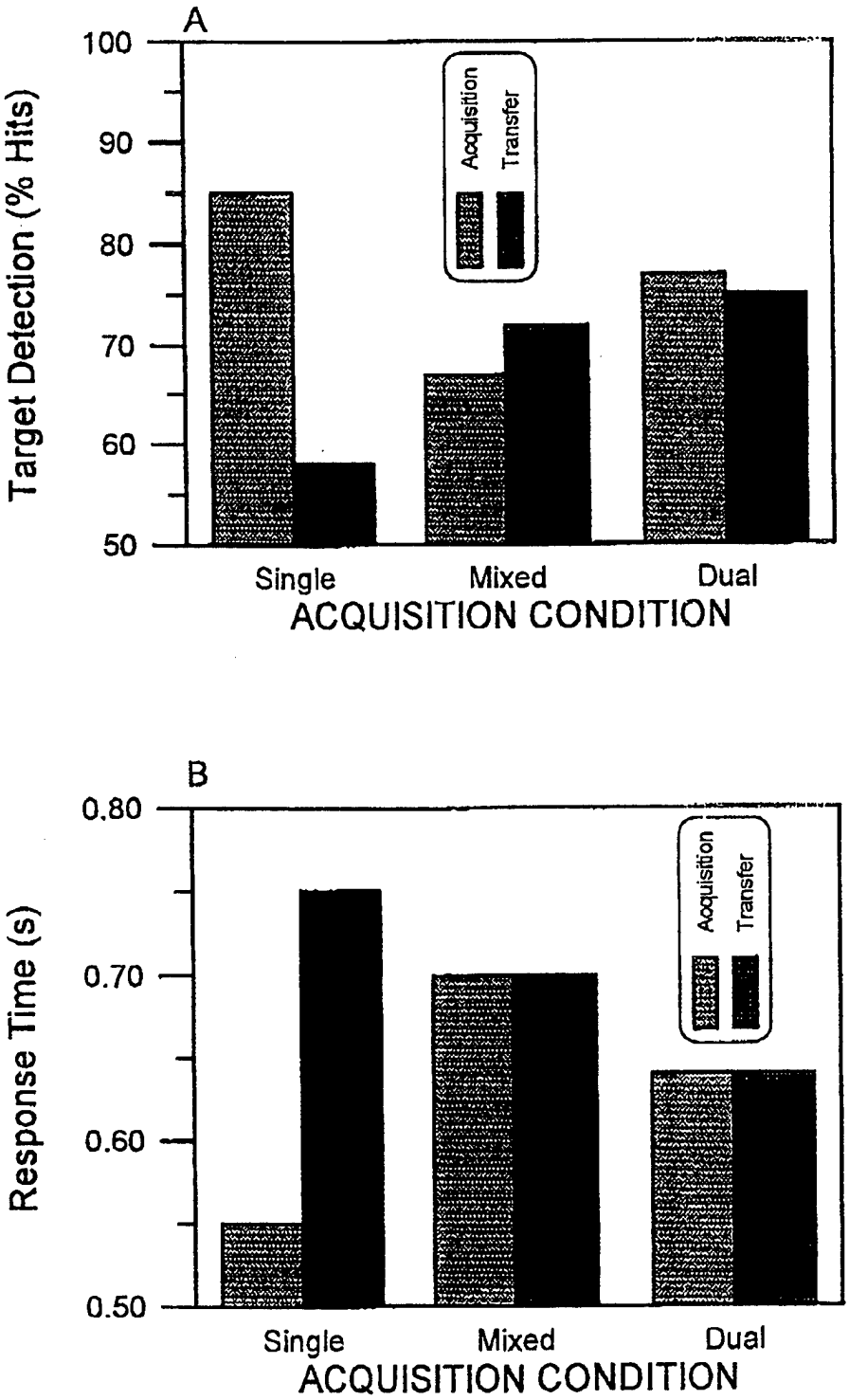
5
SESSION

Fig. 2


A
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Target Detection (% Hits)
Acquisition
Transfer
Single
Mixed
Dual
ACQUISITION CONDITION
B
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0.70
0.60
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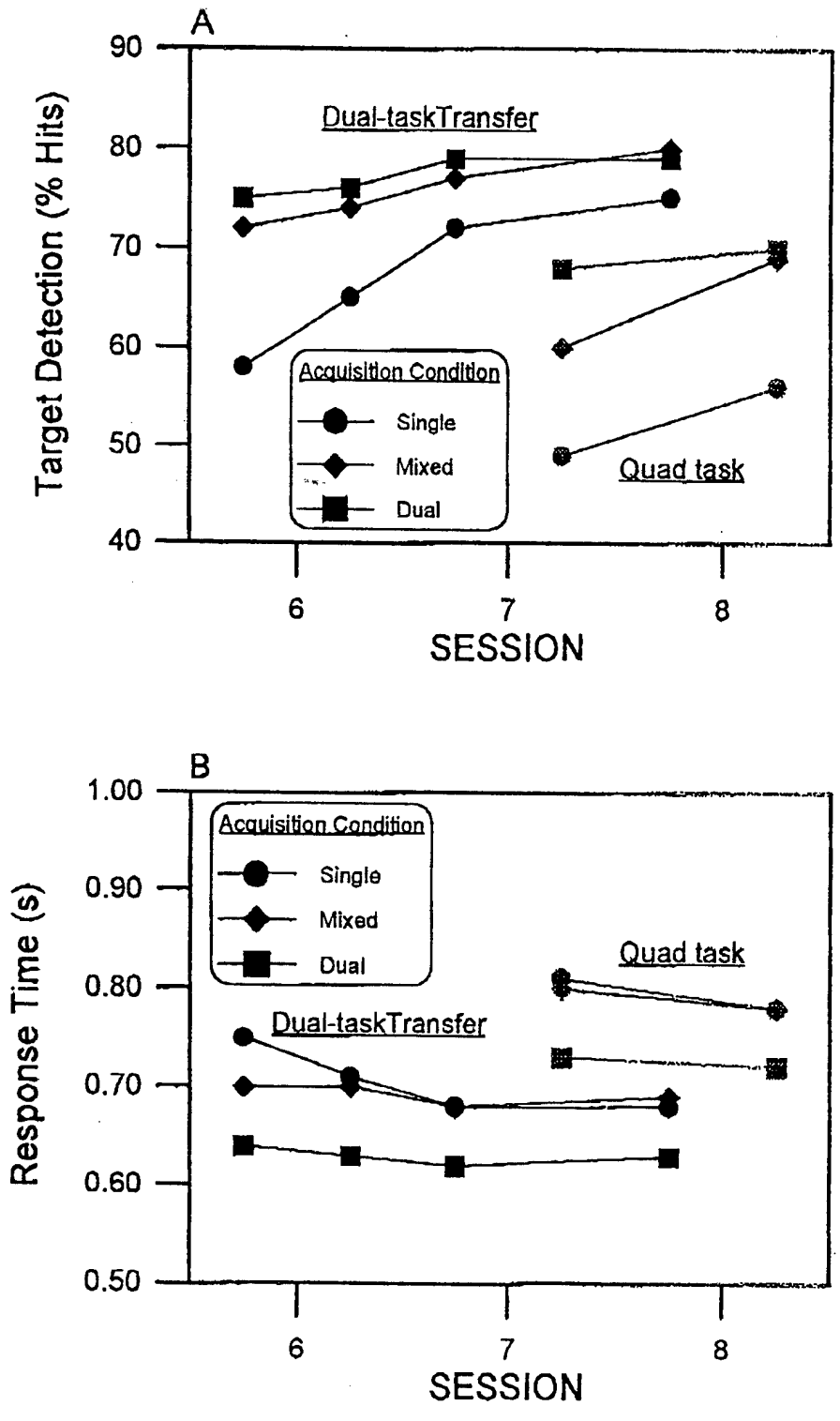
Response Time (s)
Acquisition
Transfer
Single
Mixed
Dual
ACQUISITION CONDITION

Fig. 3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Target Detection (% Hits)
Dual-taskTransfer
Acquisition Condition
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Dual
Quad task
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7
8
SESSION
B
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0.90
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Response Time (s)
Acquisition Condition
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Quad task
Dual-taskTransfer
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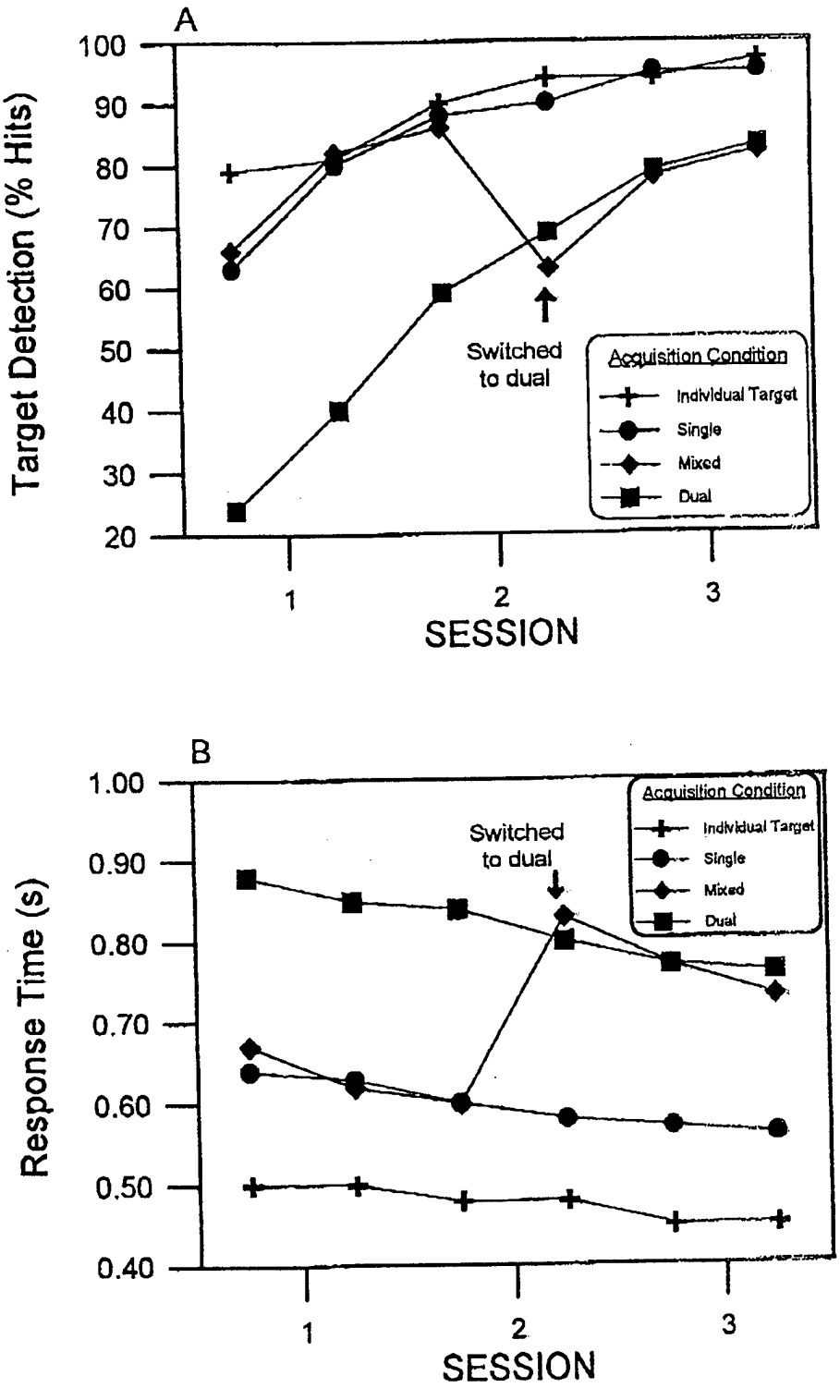
SESSION

Fig 4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Target Detection (% Hits)
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90
80
70
60
50
40
30
20
Switched
to dual
Acquisition Condition
Individual Target
Single
Mixed
Dual
1
2
3
SESSION
B
Response Time (s)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
Switched
to dual
Acquisition Condition
Individual Target
Single
Mixed
Dual
1
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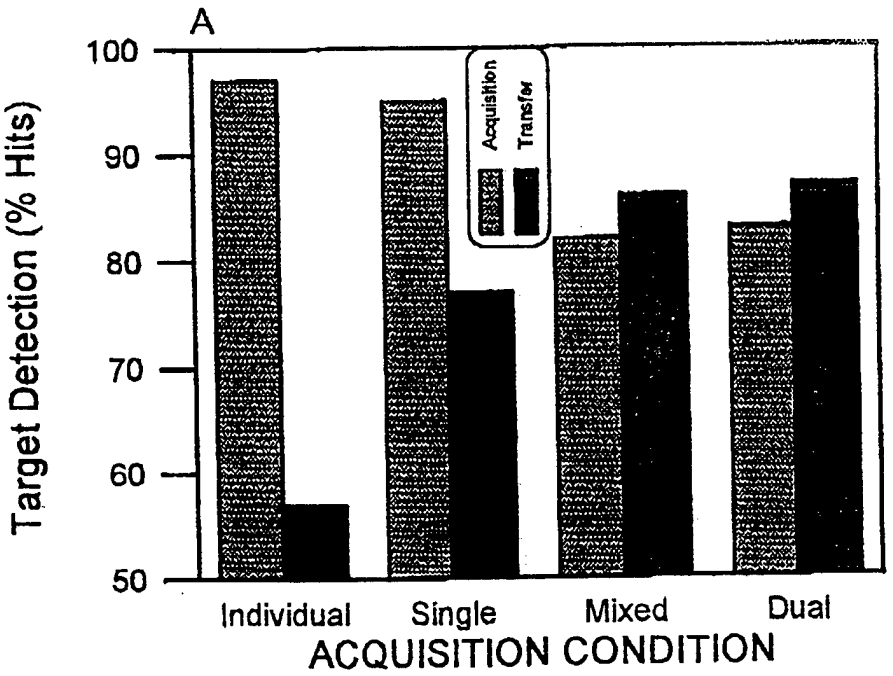
Fig. 5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Individual
Single
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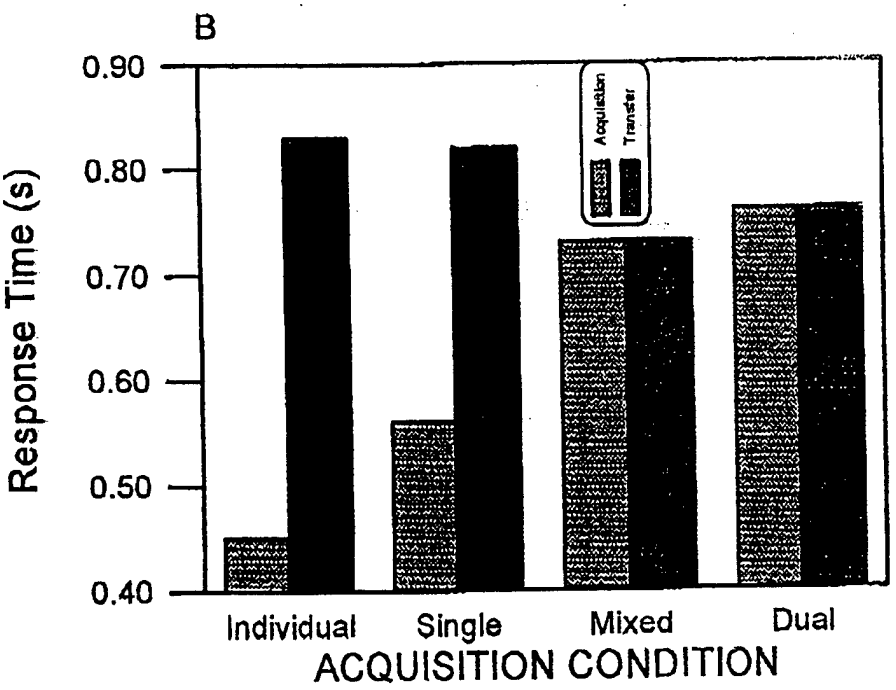
Dual
ACQUISITION CONDITION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Response Time (s)
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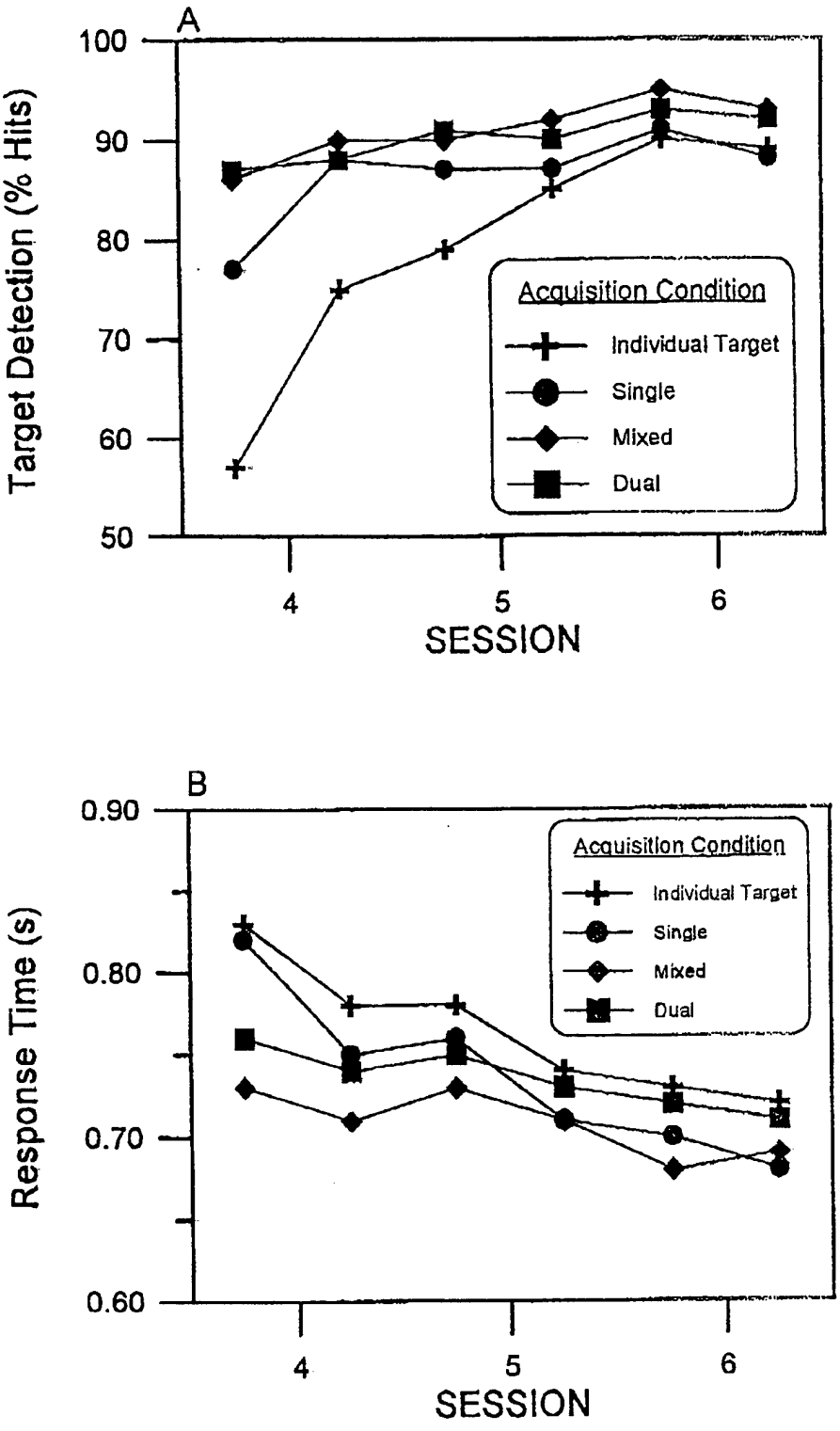
ACQUISITION CONDITION

Fig. 6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60
50
Target Detection (% Hits)
4
5
6
SESSION
Acquisition Condition
Individual Target
Single
Mixed
Dual
B
0.90
0.80
0.70
0.60
Response Time (s)
4
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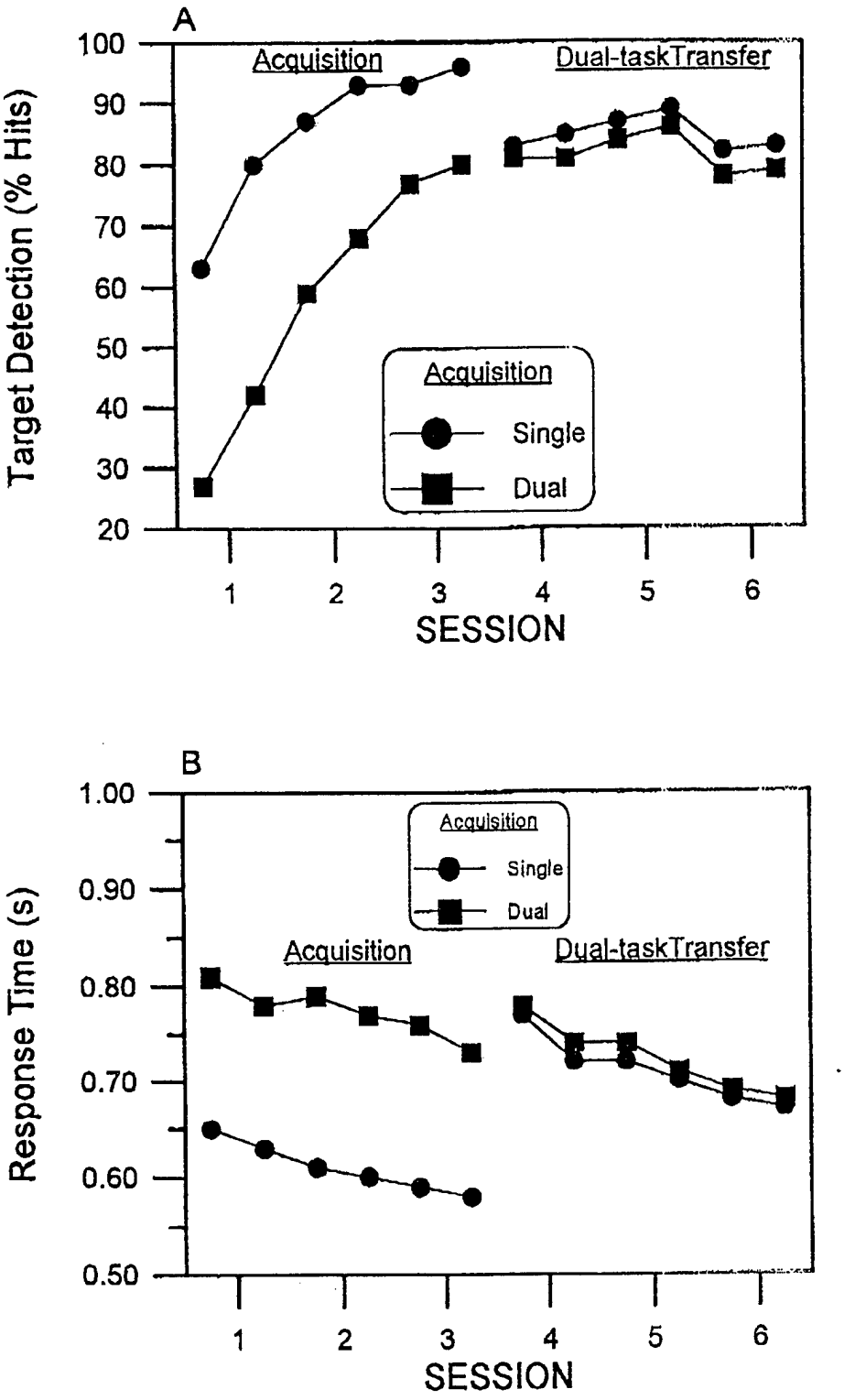
6
SESSION
Acquisition Condition
Individual Target
Single
Mixed
Dual

Fig. 7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Acquisition
Dual-taskTransfer
Target Detection (% Hits)
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80
70
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20
Acquisition
Single
Dual
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SESSION
B
Response Time (s)
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0.80
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Acquisition
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Acquisition
Dual-taskTransfer
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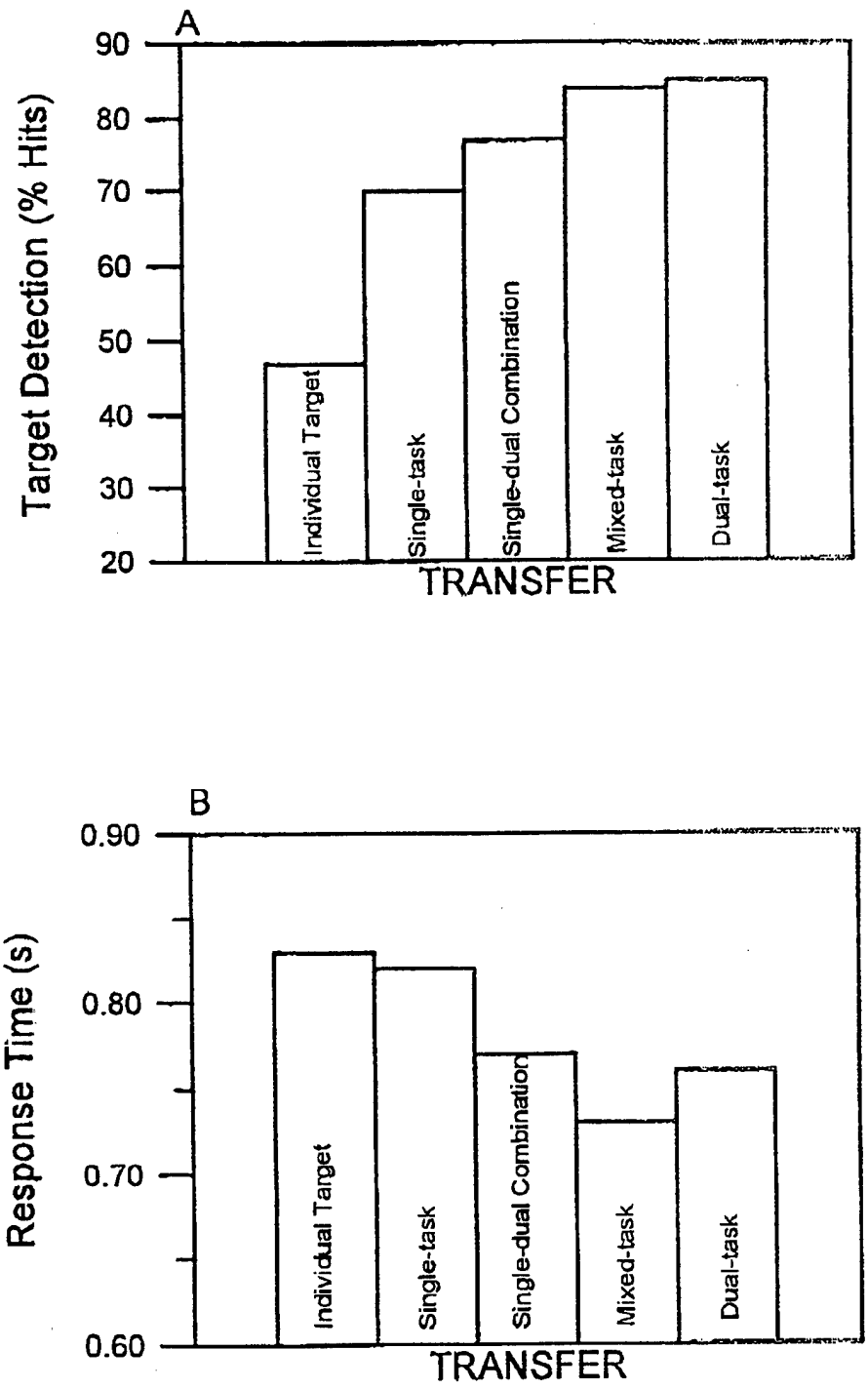
SESSION

Fig. 8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Target Detection (% Hits)
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Individual Target
Single-task
Single-dual Combination
Mixed-task
Dual-task
TRANSFER
B
Response Time (s)
0.90
0.80
0.70
0.60
Individual Target
Single-task
Single-dual Combination
Mixed-task
Dual-task
TRANSFER

Fig. 9